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Design and construction of a two-force towing balance for the Robinson Model Basin.

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DESIGN AND CONSTRUCTION OF A TWO-FORCE TOWING BALANCE FOR THE ROBINSON MODEL BASIN

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DESIGN AND CONSTRUCTION OF A

TWO-FORCE TOWING BALANCE

FOR THE ROBINSON MODEL BASIN

23

A Thesis

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by

LT. David Louis Soracco, USN

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ACKNOWLEDGEMENTS

The author is indebted to Professor Cedric Ridgely-Nevitt for his helpful guidance and many beneficial recommendations.

The author is also indebted to Mr. Duncan Robb, machinist extraordinary, for patient instructions, timely suggestions, and for his aid in making several of the fittings used in the construction of the balance. When confronted by a seemingly impossible situation, his cheery response, "They may tie us, but they won't lick us," and a careful second look made the solution easier.

Acknowledgement is made to the David W. Taylor Model Basin for the manufacture of the strut and hydrofoils used to test the balance performance.

TABLE OF CONTENTS

INTRODUCTION

This thesis is an endeavor to design and build a mechanical towing balance that is capable of measuring two forces simultaneously. The balance will be used in the Robinson Model Basin, located at Webb Institute. Weights and springs will be employed to measure the lift and drag forces produced by towed hydrofoils or other models.

If the design proves to be successful, it is intended to use the balance for towing small hydrofoils at low Reynolds numbers. As a result of these tests, a comparison will be made with current data obtained in larger model tanks and wind tunnels.

Preliminary background reference reading concerning mechanical balances presently used in model basins and wind tunnels proved to be of little value to the author for his design. Most of the balances are of the strain gage, variable inductance, or fixed platform type. The strain gage and variable inductance type balances rely on remotely located electrical equipment for measuring forces and recording data. Consequently, instrumentation is complicated and expensive, interpretation of data is time consuming, and maintenance requires specialized personnel. Fixed platform type balances used in wind tunnels are not suited for small basins.

The low and high capacity spring-weight balances used in the Robinson Model Basin offered the best available information in relation to design principle, construction and arrangement for this particular type of balance. During the

design and construction of the two force balance, frequent reference was made to these two balances.

Section 1: Preliminary Balance Design

During the design study, the following features were considered necessary in order to fulfill the requirements and functions of a two force balance.

(a) Mutually independent force measuring arrangement mounted on a common carriage.

(b) Two independent weight pan arrangements.

(c) Two independent spring arrangements.

(d) Two independent pointers and pointer indicators to measure spring deflection.

(e) Two independent arrangements for spring calibration.

(f) Provision for maintaining the hydrofoil or other model in a fixed attitude at all times.

(g) Two independent systems for counterbalance.

(h) Two independent systems to limit balance arm travel.

In addition, the following items were considered in order to increase the versatility of the balance.

(i) Means to adjust angle of attack.

(j) Adjustable depth setting.

As a result of the preliminary study during which several possible designs were mentally manipulated, the best scheme appeared to be a combination of two parallelograms. One parallelogram is suspended from pin joints from a carriage mounting, and the second parallelogram is supported by similar joints from the first.

Section 2: Detailed Description of Design Development of Component Functions

As mentioned previously, the basic design consists of two parallelograms. Refer to Figure 1.* The vertical arms, A and B, are suspended from the fixed mounting which is attached to the towing carriage. The horizontal tee-arm, C, is supported by arms A and B. In turn, tee-arm C supports two horizontal arms, arm D at the upper extremity, and arm E at the lower extremity of the tee. Arm F connects the right ends of arms D and E. To complete the picture, attach a strut supporting a hydrofoil to arm F.

A lift force transmitted from the hydrofoil to arm F will cause arms D and E to rotate about pivot points 5 and 6. Arms A and B, and tee-arm C, will not be affected by this lift force. Their original positions remain unchanged.

On the other hand, when a drag force is transmitted to the balance, arms A and B will respond and rotate about pivot points 1 and 2. Tee-arm C and arms D and E will be displaced horizontally and vertically. However, arms D and E will not rotate about their pivots.

Notice in both instances that the attitude of the hydrofoil does not change.

During actual towing, both events will take place simultaneously. Thus, the above arrangement satisfies design requirement (a) and (f) on page 3.

In order to measure the force transmitted to arms A and B, a system consisting of pan weights and springs is utilized. If the pan weights do not balance the imposed force within the limits of balance travel, the spring is used to measure the

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*All figures are in the appendix.

difference. The spring is usually calibrated by adding known weights to the balance and noting the corresponding deflections on a pointer indicator.

To incorporate this system in the balance for drag measurement, a horizontal arm had to be added to the arm A at point 1 (see Figure 2). This additional arm is necessary in order to keep the weight pan and spring in a vertical position. From the left side of the cross-arm, is suspended a weight pan. The lower end of the weight pan is connected to a guide arm which is pivoted on an extension from the fixed mounting. With this arrangement, the weight pan will always remain in a vertical attitude.

A spring is added to the right side of the cross-arm. The upper end of the spring is fixed to an extension of the mounting.

In order to measure the amount of spring deflection, a pivoted pointer and pointer indicator is added. One end of the pointer is connected to the left side of the cross-arm by means of a bar link. A pointer can serve two purposes. First, it indicates spring deflection and second, it can be designed to magnify the initial spring deflection.

There are several items to be considered in pointer design (refer to Figure 3).

(a) The distance (a) between the link connection and the pivot point of arm A should be as long as possible. The longer the distance (a), the greater will be initial arc travel.

(b) For arc travel magnification, the ratio of (c) to

(b) should be as large as practical.

(c) The length of link (d) plus the length of pointer arm (b) determines the limit of travel of arm A.

Referring to Figure 2 again, the pointer is connected to the left side of the cross-arm by a link. The pointer pivot and pointer indicator are located on an extension from the fixed mounting.

A fixed pin is added to the extreme right end of the cross-arm for the purpose of adding weights when the spring is calibrated.

Finally, initial counterbalance is achieved by including an additional extension to arm A. This extra arm extends above the point 1, and has a sliding weight attached to it. Arm A supports most of the balance weight and whenever arm A is displaced from its initial vertical position, a moment will be acting on arm A to oppose this deflection. The counterbalance will therefore tend to compensate for this moment.

This completes the items required for the measurement, indication, and counterbalance of the horizontal or drag force section of the balance.

As mentioned previously, tee-arm C supports arms D and E which are involved in the measurement of vertical or lift forces.

A spring is attached to the left side of arm E (refer to Figure 4). The upper end of the spring is fastened to an extension from tee-arm C.

The pointer pivot is located on an extension from tee-arm C. The pointer indicator is secured to tee-arm C as shown in

Figure 4. The pointer is linked to the left side of arm D.

Arm F is actually two separate arms which are connected to arms D and E by points 7 and 8. One arm contains a pan weight platform and the other contains a means for varying the angle of attack and also for mounting the strut and hydrofoil.

The angle setter consists of two parts. The lower part which is connected to point 8 has degree settings from 0° to $\pm 10^{\circ}$. In addition, it has a slide on which the strut is mounted and by means of which the strut depth can be varied. The upper part is a clamp which is connected to point 7. The clamp has an index for setting the desired angle. However, the two parts are so designed that the distance between points 7 and 8 remains the same for any angle setting.

Counterbalancing is achieved by adding weights to the left side of arm E and by a sliding weight to the left side of arm D.

Lift arm travel is governed by upper and lower limit stops located on tee-arm C and acting on arm E.

This concludes the balance design requirements as listed on page 3.

Section 3: Balance Construction

Prior to the construction of the balance, a permanent storage stand was made for the balance. The stand was constructed with several adjustable connections so that the track, on which the balance mounting slides, can be lined up in three mutually perpendicular planes. When the balance is ready for final alignment, bubble levels can be used to compare the balance alignment with the stand alignment.

From the description of the balance, it would appear that all the arms are in a single plane. Actually, the arms A, B, D, E and tee-arm C are symmetrical pairs of arms rigidly joined together to form a rectangular framework. As an aid to fabrication, one common length of each pair of arms was machined true in a horizontal milling machine. Machining a common length for each pair provided an accurate reference for dimensions and alignment. Also, a layout table could be used for setting up the arms and checking the arm framework for squareness.

As a matter of interest, the milling machine and horizontal planer were used to machine many of the parts that required accurate dimensions or that were going to be used for dimension reference.

During the entire balance construction, an effort was made to measure the initial dimensions as accurately as possible. Thus, initial alignment would be kept within close tolerances. In order to provide for slight adjustment during final alignment, many of the screw holes were drilled slightly over-sized. Shim material can also be used as an aid for alignment.

The author will not attempt to give all the steps in the construction of the balance. However, Figure 5 will outline the important dimensions for pivot points, length of lever arms, and alignment. Details, such as bearings, bearing caps and other pertinent information are also included in Figure 5.

Section 4: Calibration and Testing

In addition to building the balance, the author intended to calibrate the balance and run a few trial tests. After all the many hours spent in the machine shop constructing the balance, the author would like to have the satisfaction of knowing whether or not the balance will perform as intended. Unfortunately, the formal thesis deadline is a few days ahead and the results of this phase of balance checkout cannot be included in this writing. However, with time and the academic schedule permitting, the author will try to complete calibration and conduct a trial test before the completion of this academic term. If this phase is completed, a supplement will be included in this thesis.

The author would like to outline a method for calibration.

(1) Prior to calibration, the balance, including the strut and hydrofoil, should be statically balanced until the springs are slightly under tension. For the drag section, weights are clamped to the arm extending above point 1. For the lift section, weights can be added to the left side of arm E, and final adjustment can be made with the sliding weight on arm D. The lift balance should be counterbalanced first.

(2) Calibrate the lift section spring by adding weights to the left side of arm D. Record the corresponding spring deflections from readings on the pointer indicator.

(3) Calibrate the drag section by adding weight to the right side of the cross-arm on arm A. Record the corresponding spring deflections from readings on the pointer indicator.

(4) After the calibration curves are plotted, testing can be started.

The next step is to investigate the forces acting on the strut when towed alone. This is necessary in order to separate the forces when the strut and hydrofoil are towed together.

The proposed towing procedure for strut calibration follows:

(1) Calibrate the balance springs with strut attached.

(2) Position the strut at the bottom of the slide.

(3) Tow the strut. Vary angles of attack from $-10°$ to $+10°$.

(4) Record pan weights and pointer indicator readings for each run.

(5) Reposition the strut slightly higher on the slide. Continue the above procedure until the complete range of strut depths is covered.

It should be noted that the wetted surface of the strut is always varying. For example, when traversing the range of angles of attack at a certain slide setting, the geometry of the mechanism will cause the strut depth and strut angle to the water line to change. If the lift arms D and E are displaced upwardly from the horizontal plane during towing, the wetted surface of the strut will be reduced still further.

By knowing the geometry of the angle setter, the strut position on the slide, and the height of angle setter pivot point above the water line, the wetted surface of the strut can be determined for all slide settings and angles of attack.

To determine the change in wetted surface when the strut is actually towed is another exercise in geometry. In this case, the dimensions of arms A, B, D, E, F, cross-arm C, and the geometry of the angle setter including the strut position on the slide must be used. For this procedure, a combination

of vertical and horizontal displacements should be given the balance lift and drag sections. Corresponding pointer indicator readings should be taken for each displacement combination. The wetted surface can then be determined for each displacement. This information can be used during actual towing simply by noting the pointer indicator readings.

Once the wetted surface of the strut is known for each position of towing, the resistance (or in this case, drag) coefficient can be determined by normal procedure. Plotting the drag coefficient against angle of attack should produce a smooth curve. If this is so, then the strut forces can be determined when the hydrofoil is attached and towed. If this is not so, further investigation will be necessary.

Assuming that the forces acting on the strut can be determined, the next step is to tow the strut and hydrofoil together. The proposed procedure follows:

(1) Calibrate the balance springs with the strut and hydrofoil attached.

(2) Tow the hydrofoil at various angles of attack.

(3) Record pan weights and pointer indicator readings.

(4) Deduct strut forces.

(5) Compute the C_D and C_L for the hydrofoil.

Section 5: Conclusions

1. The best arrangement for measuring drag and lift forces simultaneously by means of a balance utilizing weights and springs is one parallelogram mounted within another as described in this thesis.

2. It is felt that the balance design is fundamentally sound. However, proof of good performance will depend on the results of calibration and trial tests.

3. For future projects of a similar nature, the author recommends that complete working models be developed in lieu of working drawings. With regard to this design, many of the measuring and indicating system components were not fully developed until all the arms were fabricated and in position. The author regrets having spent so much time trying to develop the complete design on the drawing board. Much of the design had to be revised or completely changed during actual construction.

4. Although the author hoped to learn something about machining and the technique involved in the construction of a precision instrument, lack of experience proved to be detrimental and at times utterly frustrating during the construction phase. In the future, if any students contemplate doing a similar project, it is recommended that a team of at least two be mandatory. Included in the team should be at least one student who considers himself a fair machinist. There are also many occasions when four hands are better than two.

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Hotz, G.M. and McGraw, J.T., "The High Speed Water Tunnel Three-Component Force Balance," California Institute of Technology. Report No. 47-1, January 1955.

Loftin, L.K., Jr. and Smith, H.A., "Aerodynamic Characteristics of 15 NACA Airfoil Sections at Seven Reynolds Numbers from 0.7 x 10^6 to 9.0 x 10^6," NACA TN 1945, October 1949.

SOURCES OF SUPPLY

1.	Charles of Glen Cove:	27 School St. Glen Cove, N.Y.
2.	Patterson Brothers:	15 Park Row New York, N.Y.
3.	Sears Roebuck & Co.:	52 Glen St. Glen Cove, N.Y.
4.	Steisel Hardware:	17 Glen St. Glen Cove, N.Y.
5.	Whitehead Metals Products Co., Inc.:	303 W.10th St. New York, N.Y.

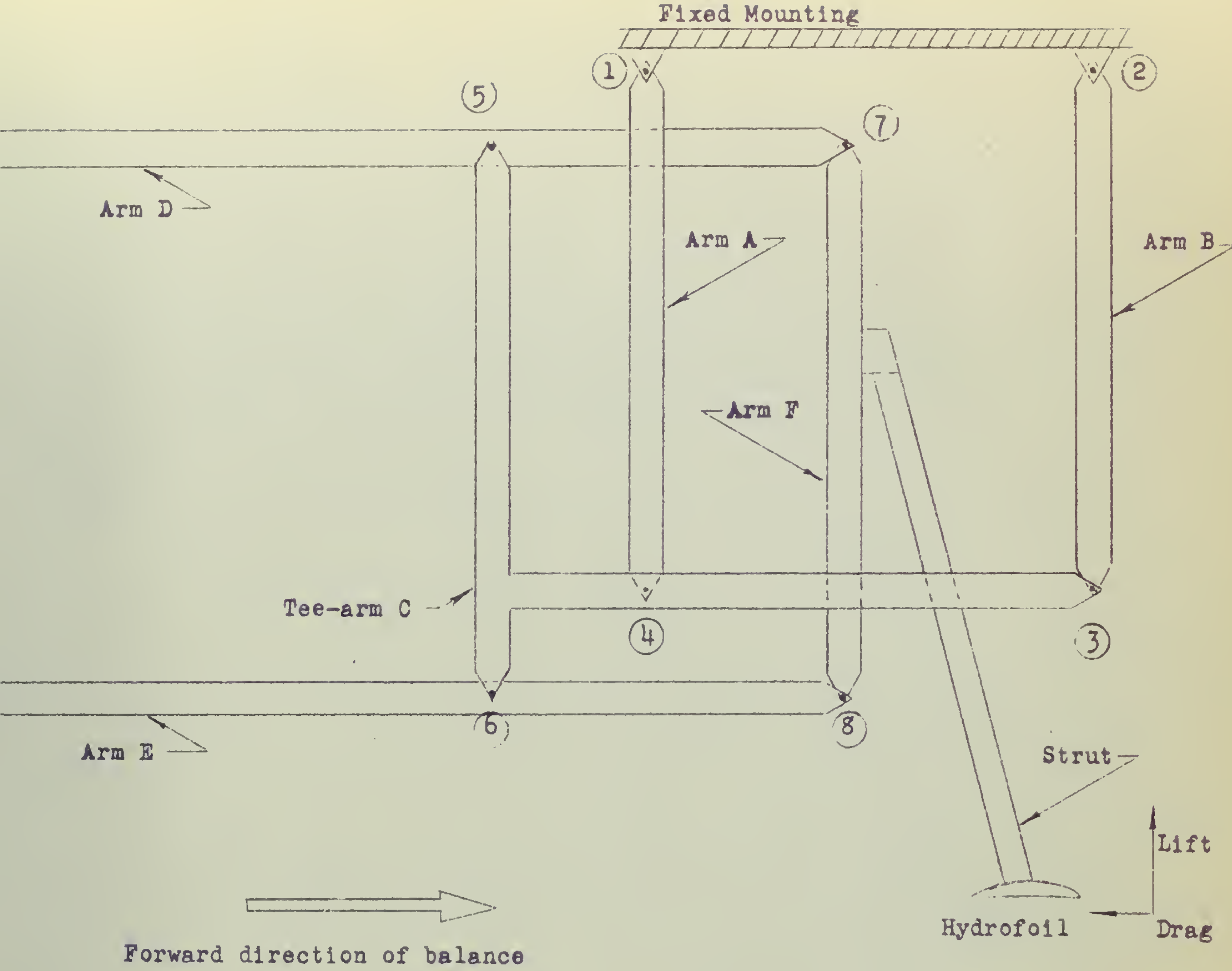


Figure 1. Schematic of Balance Framework.

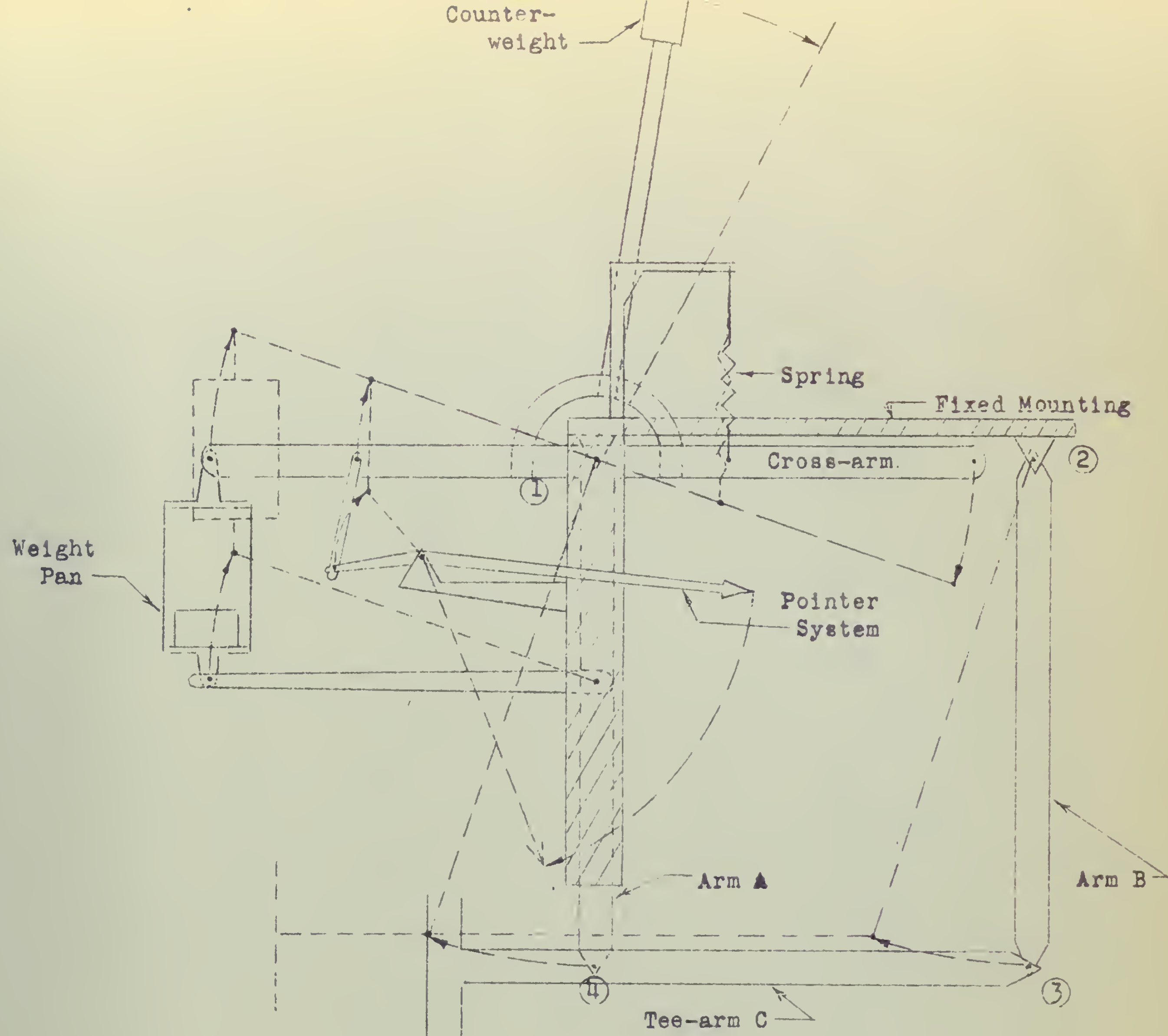


Figure 2. Drag Force Measuring and Indicating Systems.

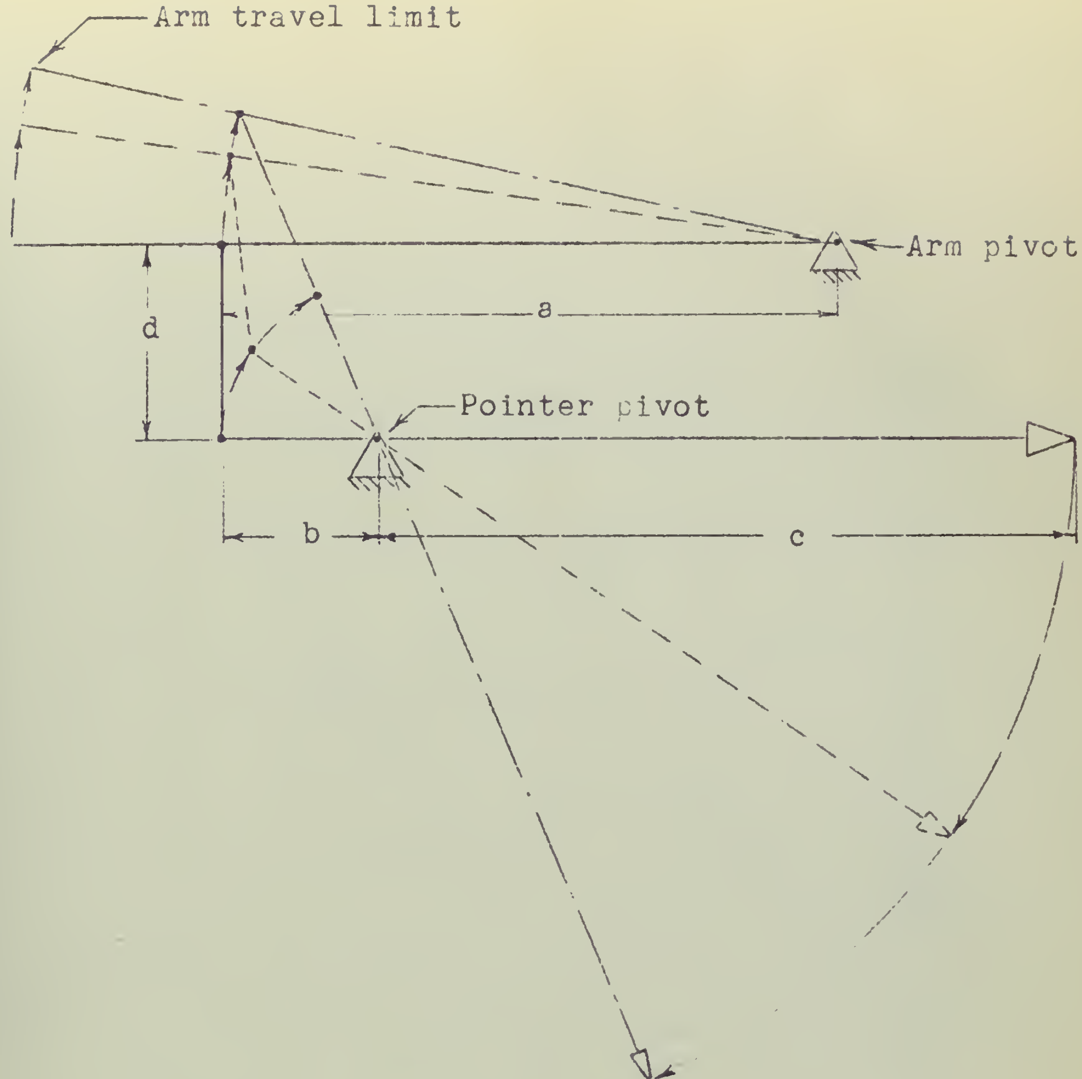


Figure 3. Pointer indicating system.

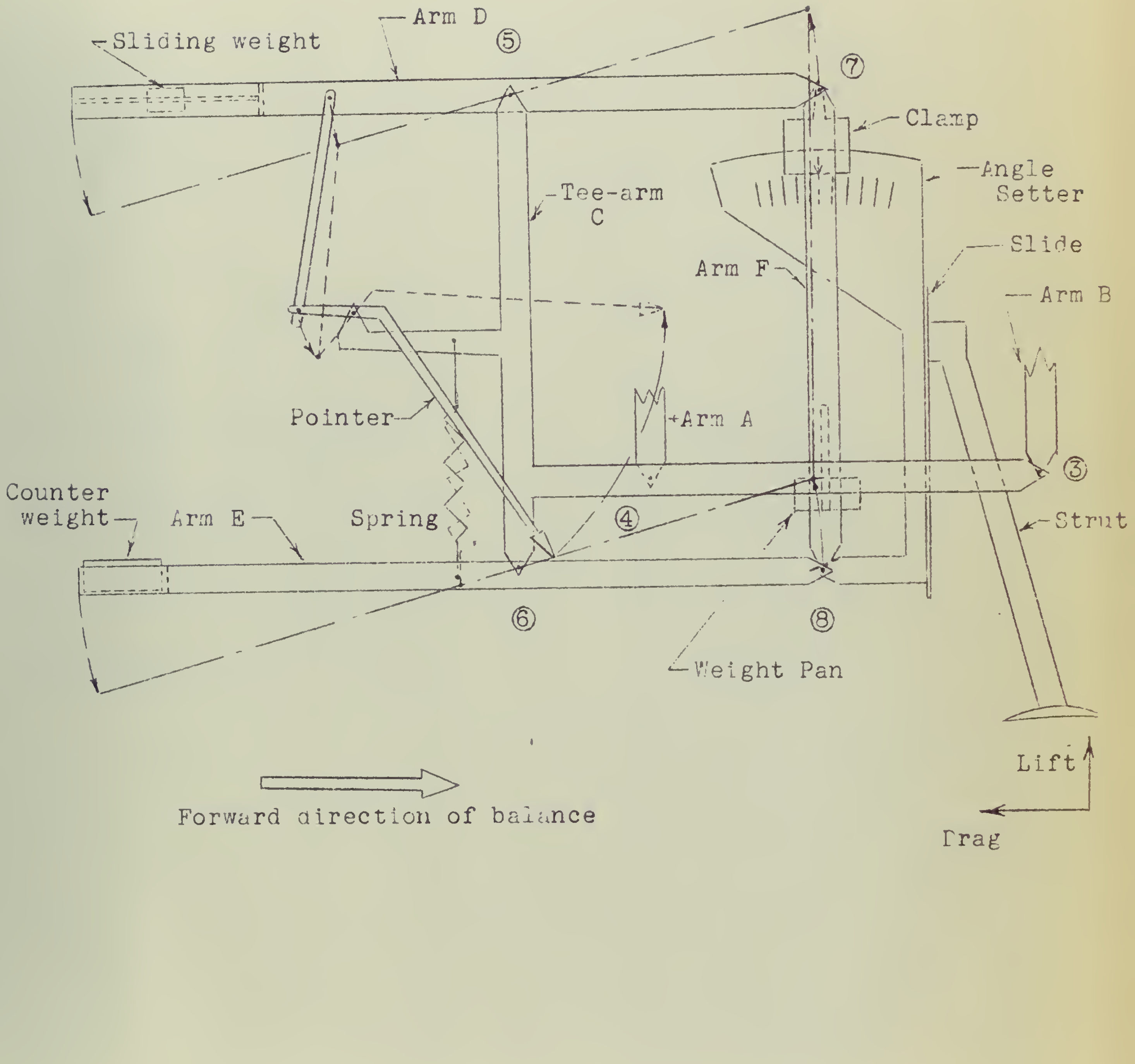
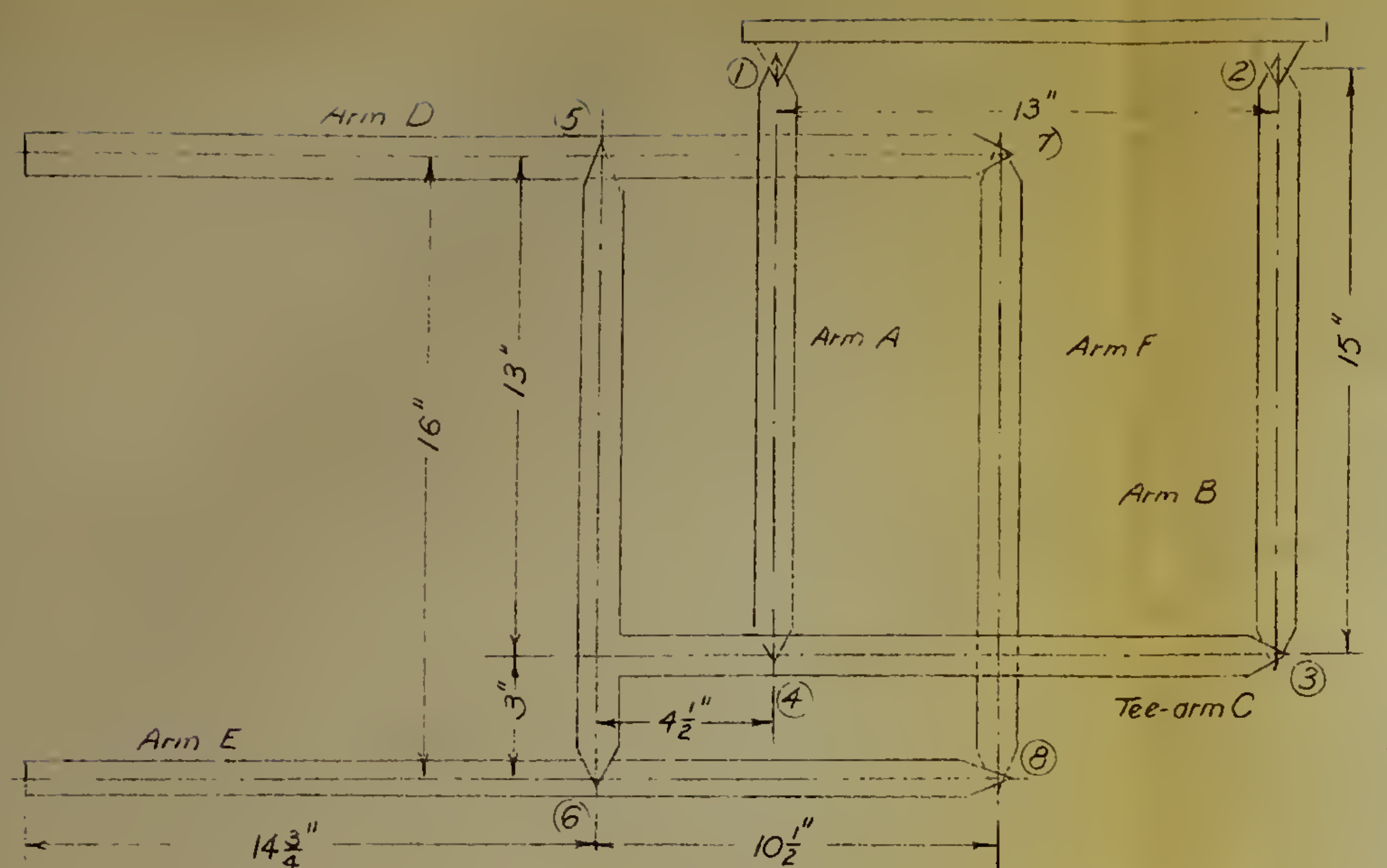
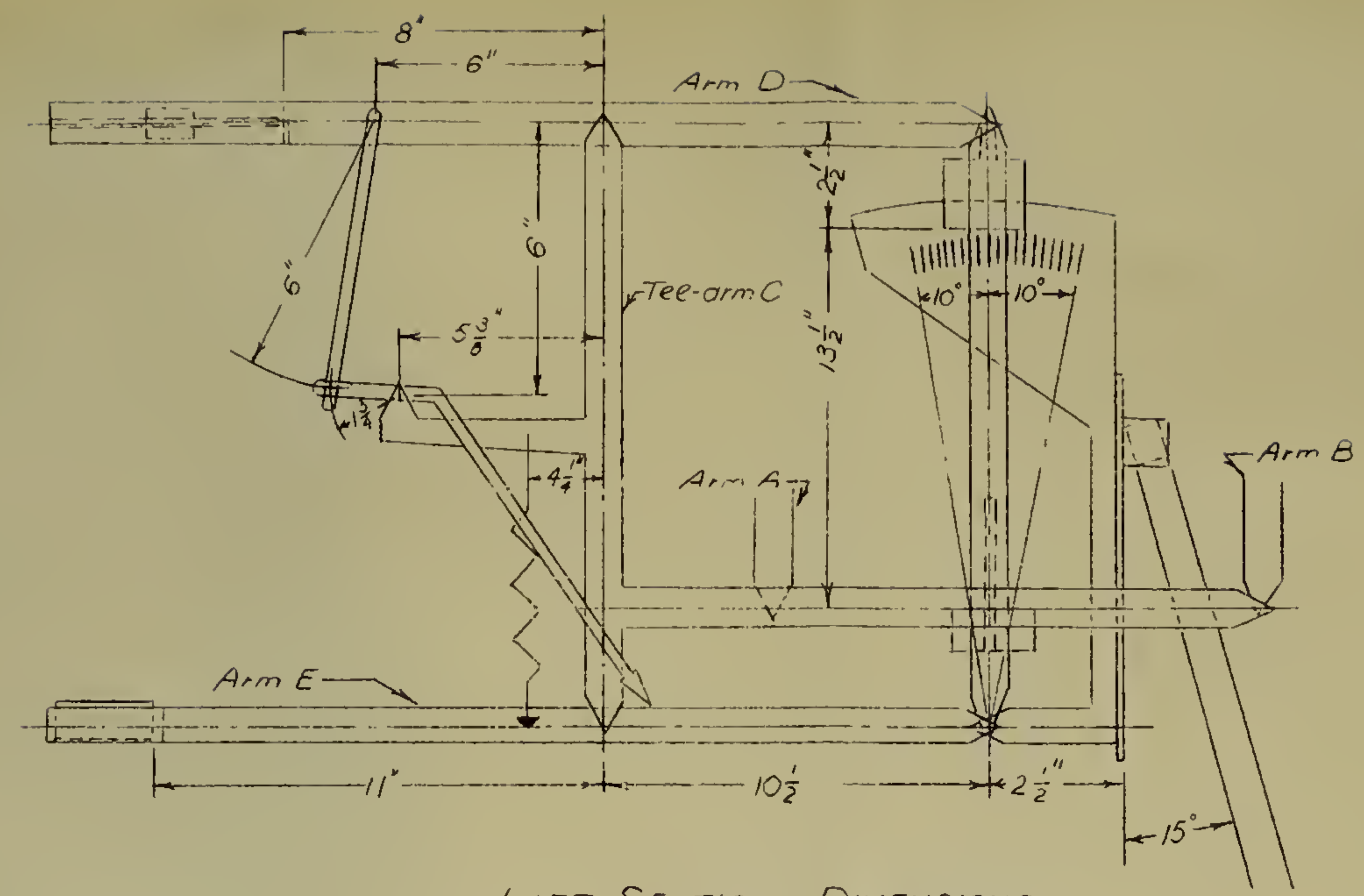


Figure 4. Lift Force Measuring and Indicating Systems.

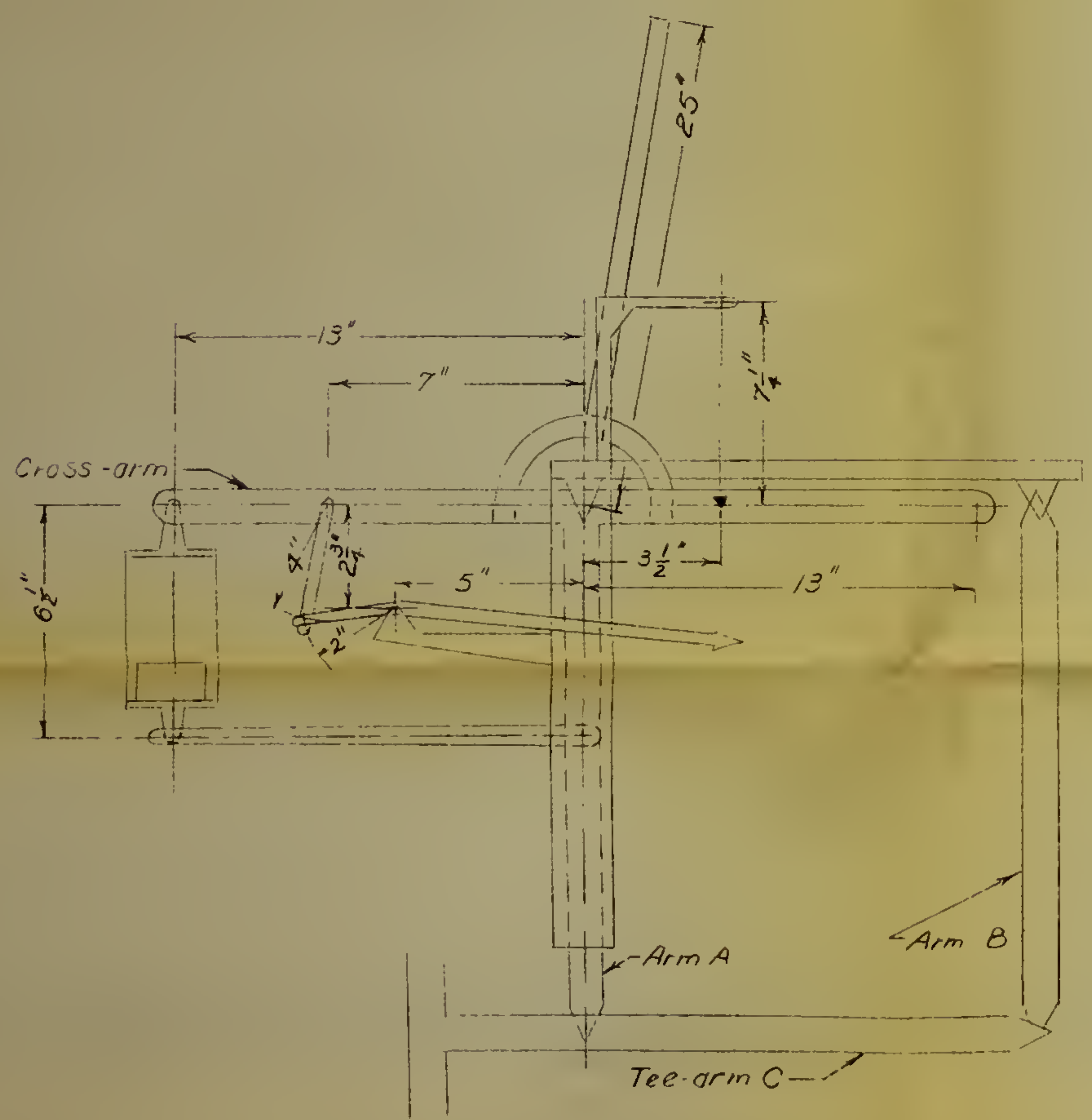


BALANCE FRAMEWORK DIMENSIONS

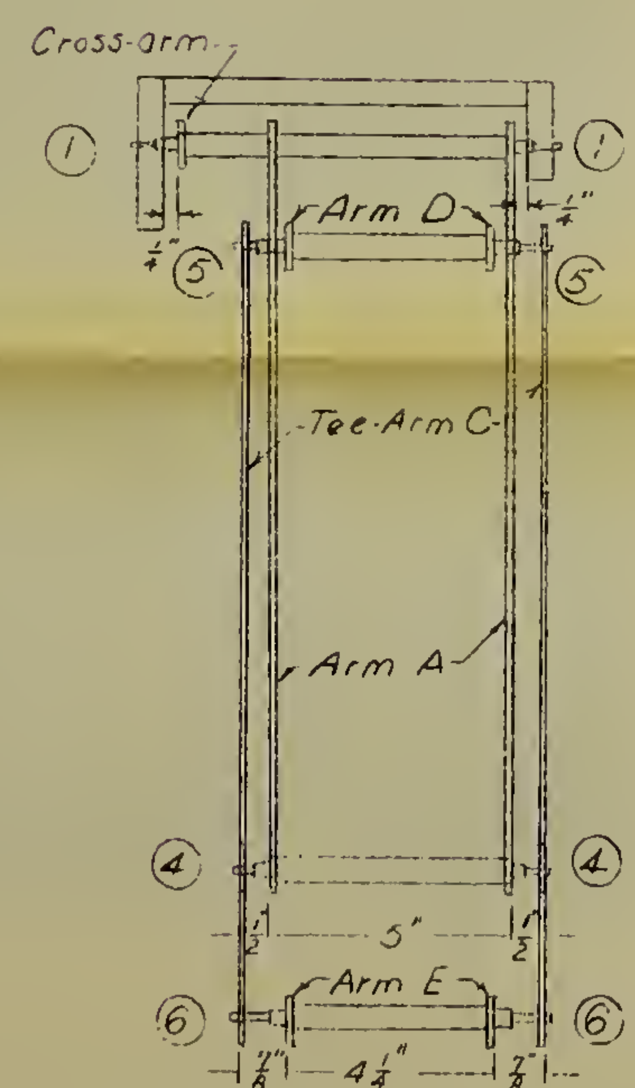


LIFT SECTION DIMENSIONS

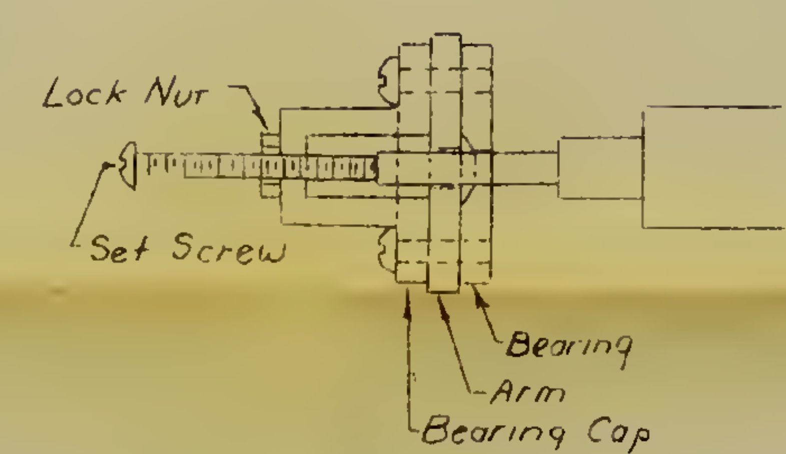
Main Bearings--	Located at points 1, 4, 5, and 6. Made from 1/8" stainless steel plate Brg. diameter 1/8", counter-sunk 1/32".
Pin Joints ----	Pin is 1/16" stainless steel round stock. All other connections are pin joints.
Arms ----	Made from 1/8" aluminum.
Main Journals -	Made from 1/2" stainless steel round bar. Journals are 1/8" diam.
Bearing Caps---	Made from 1" brass round bar.
Screws -----	2-56 brass machine screws 4-36 " " " 10-32 " " " 12-24 " " "
Tee-arm C tie rods -- -	Large hex. tie rod has 1/4"-20 thread. Small rod has 8-32 thread.



DRAG SECTION DIMENSIONS



ALIGNMENT DIMENSIONS



MAIN BEARING DETAILS 1" = 1"

Figure 5. Balance Dimensions.

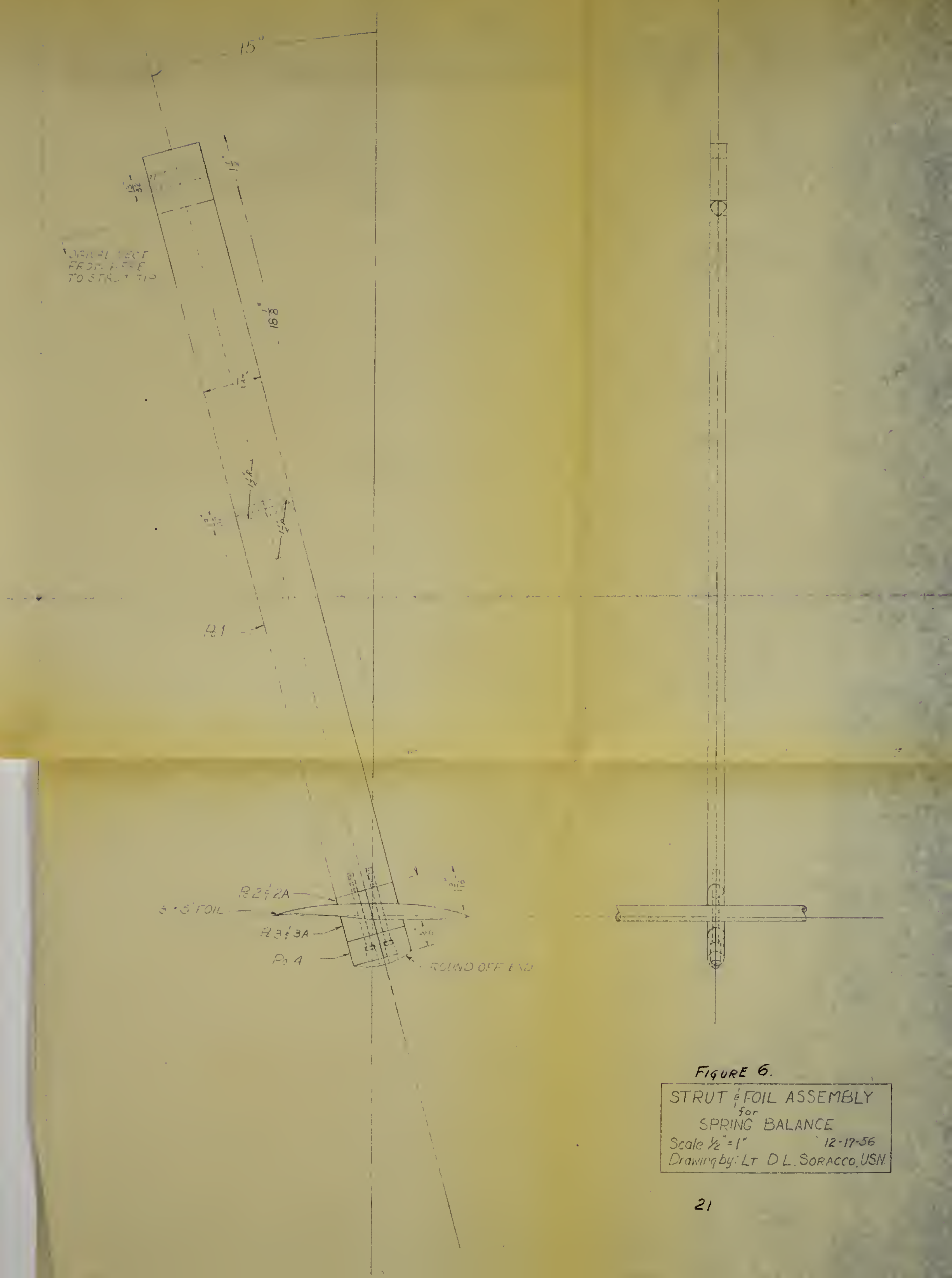


FIGURE 6.

STRUT & FOIL ASSEMBLY
for
SPRING BALANCE
Scale ½" = 1" 12-17-56
Drawing by: LT D L. SORACCO, USN.

Ordinates for NACA 64-409 Airfoil Section

Chord = 3"   Span = 18"   Foil tips rounded off

UPPER SURFACE		LOWER SURFACE	
Station (in.)	Ordinate (in.)	Station (in.)	Ordinate (in.)
0	0	0	0
0.0113	0.02487	0.0187	-0.01887
0.0184	0.03063	0.0266	-0.02223
0.0328	0.03993	0.0422	-0.02709
0.0696	0.05685	0.0803	-0.03453
0.1441	0.08196	0.1559	-0.04404
0.2189	0.10149	0.2311	-0.05061
0.2939	0.11775	0.3061	-0.05571
0.4443	0.14388	0.4557	-0.06312
0.5949	0.16368	0.6051	-0.06817
0.7456	0.17871	0.7544	-0.07131
0.8965	0.18945	0.9035	-0.07281
1.0473	0.19614	1.0526	-0.07254
1.1983	0.19896	1.2017	-0.07044
1.3492	0.19662	1.3508	-0.06522
1.5000	0.19026	1.5000	-0.05790
1.6501	0.18048	1.6493	-0.04908
1.8013	0.16782	1.7986	-0.03930
1.9518	0.15255	1.9482	-0.02895
2.1021	0.13512	2.0979	-0.01848
2.2522	0.11574	2.2478	-0.00834
2.4021	0.09462	2.3979	+0.00090
2.5518	0.07239	2.5483	+0.00837
2.7013	0.04932	2.6987	+0.01272
2.8506	0.02574	2.8494	+0.01218
3.0000	0	3.0000	0

Leading edge radius = 0.01737 inches

Slope of radius through leading edge = 0.00504

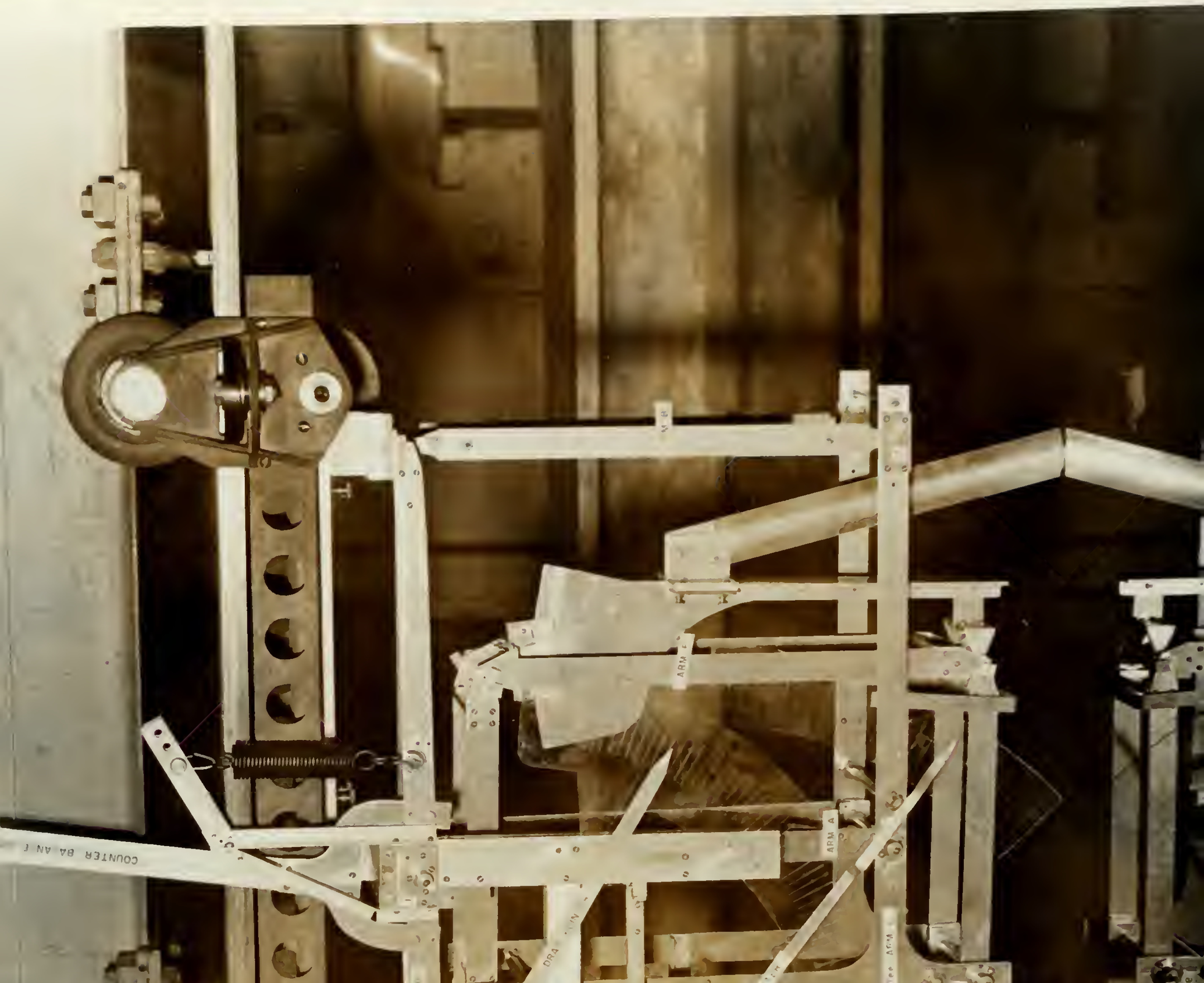
Ordinates for NACA 64-409 Airfoil Section

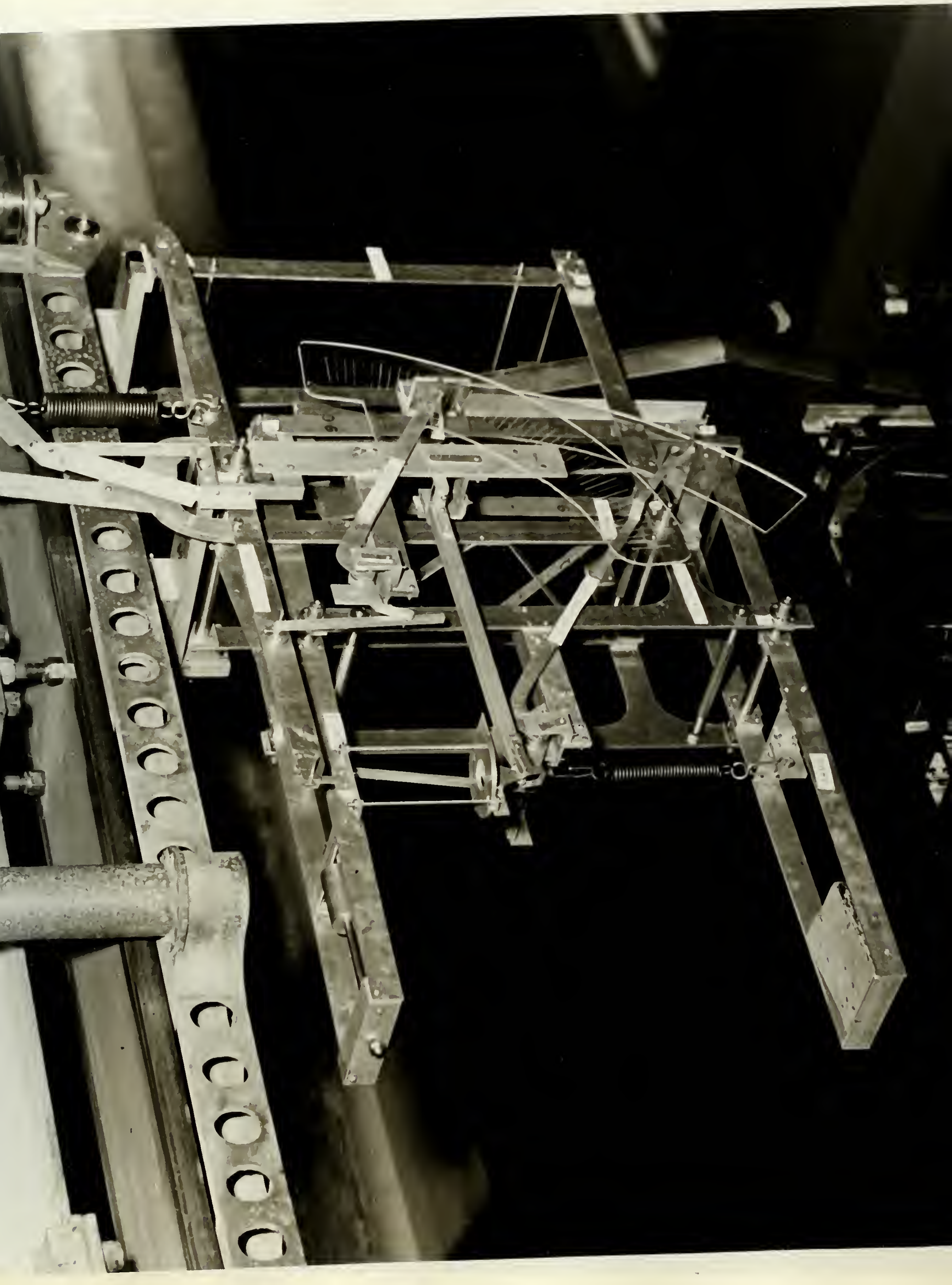
Chord = 5"   Span = 30" Foil tips rounded off

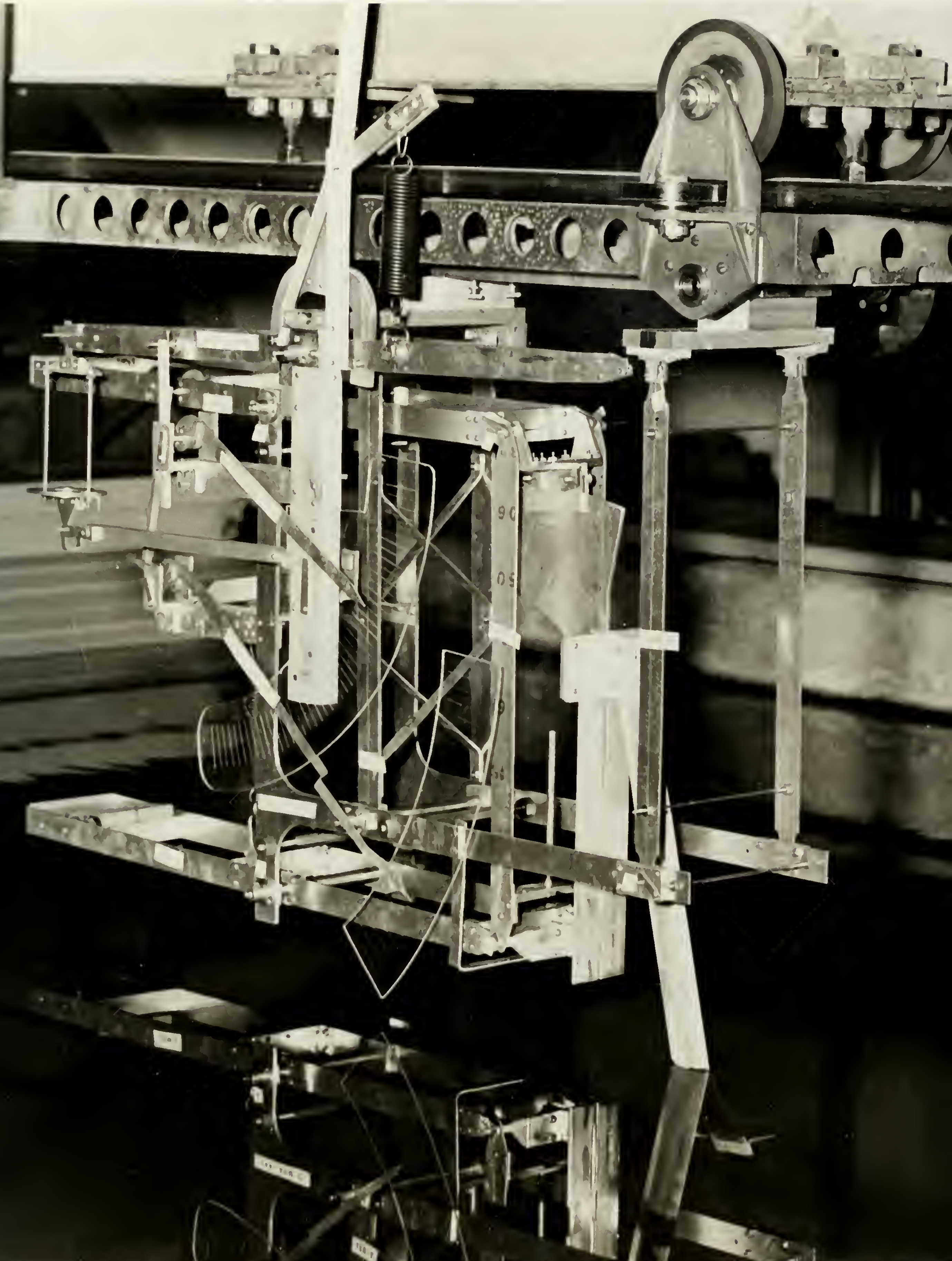
UPPER SURFACE		LOWER SURFACE	
Station (in.)	Ordinate (in.)	Station (in.)	Ordinate (in.)
0	0	0	0
0.01885	0.04145	0.03115	-0.03145
0.03065	0.05105	0.04435	-0.03705
0.05475	0.06655	0.07025	-0.04515
0.11610	0.09475	0.13390	-0.05755
0.24015	0.13660	0.25985	-0.07340
0.36485	0.16915	0.38515	-0.08435
0.48990	0.19625	0.51010	-0.09285
0.74050	0.23980	0.75950	-0.10520
0.99150	0.27280	1.0085	-0.11360
1.24270	0.29785	1.2573	-0.11885
1.49410	0.31575	1.5059	-0.12135
1.7456	0.32690	1.7544	-0.12090
1.9971	0.33160	2.0029	-0.11740
2.2486	0.32770	2.2514	-0.10870
2.5000	0.31710	2.5000	-0.09650
2.7512	0.30080	2.7488	-0.08180
3.0022	0.27970	2.9977	-0.06550
3.2530	0.25425	3.2470	-0.04825
3.5034	0.22520	3.4965	-0.03080
3.7536	0.19290	3.7464	-0.01390
4.0034	0.15770	3.9965	+0.00150
4.2529	0.12065	4.2470	+0.01395
4.5021	0.08220	4.4978	+0.02120
4.7510	0.04290	4.7489	+0.02030
5.0000	0	5.0000	0

Leading edge radius = 0.02895 inches

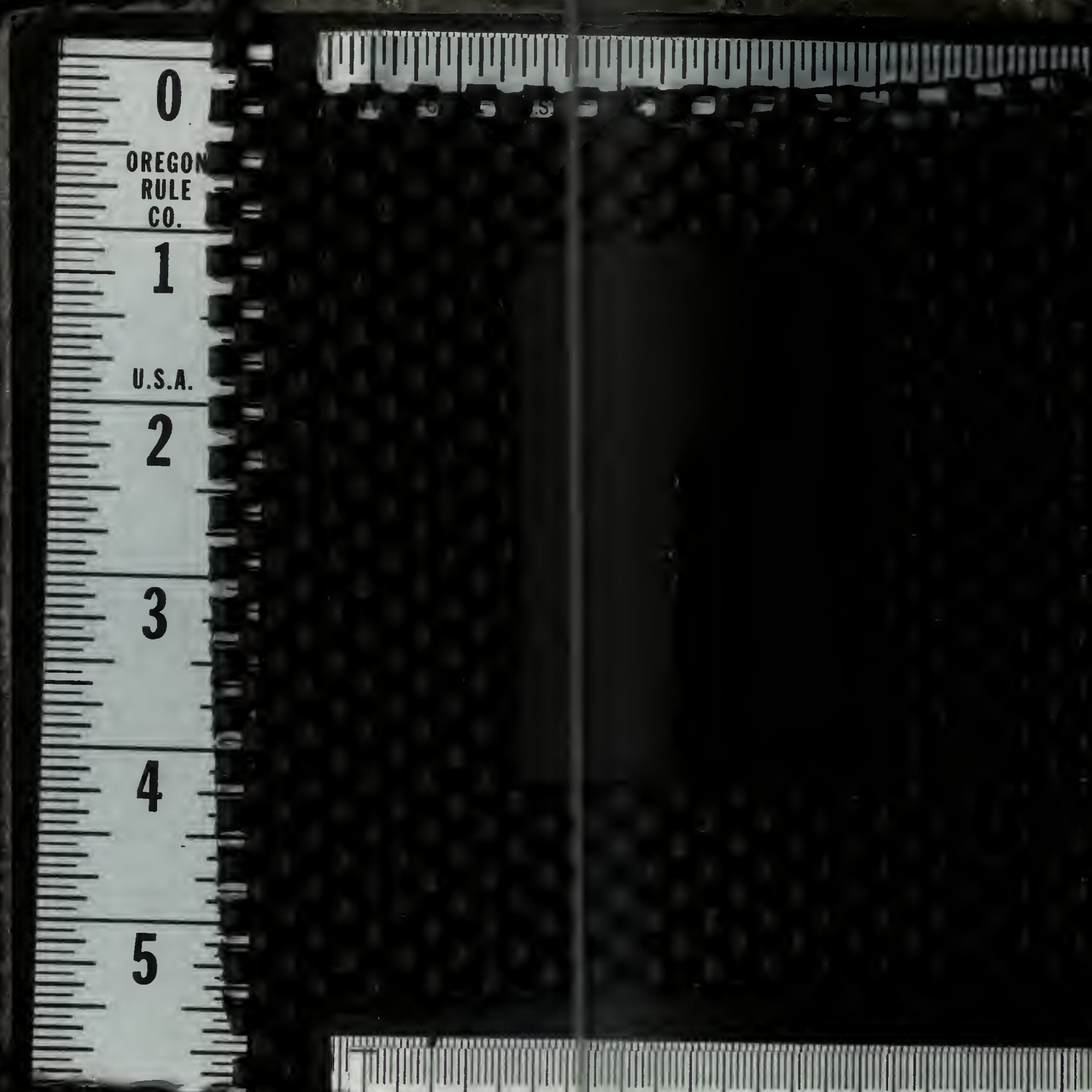
Slope of radius through leading edge=0.00840







Thesis
S6659 Soracco 35910
Design and construction of a two-force towing balance for the Robinson Model Basin.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OREGON
RULE
CO.
1
U.S.A.
2
3
4
5